Hecate Strait Project: Results of the First Two Years of Multispecies Fisheries Research

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by

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ABSTRACT

Tyler, A. V. (Editor). 1986. Hecate Strait Project: results of the first two years of multispecies fisheries research. Can. Tech. Rep. Fish. Aquat. Sci. 1470: 50 p.

The Hecate Strait Project of the Pacific Biological Station, Fisheries Research Branch, was begun in April, 1984 and will continue for five years. The goal of the project is to develop the ecological basis for approaches to mixed-species fisheries management in Hecate Strait. The landings from the area are important locally, but small on a world basis. The smallness is an advantage to research, however. The system is effectively a model of large scale situations that exist in many parts of the world that are more difficult to investigate, and whose fisheries are more difficult to manage. The 12 sub-projects that provide inter-related research results are as follows: Particle-size spectrum estimation of the standing stock of pelagic fish; Hecate Strait fish assemblage distribution surveys; Distribution of herring, and pelagic associates in winter; Estimation of abundance and sizes of salmon species in the Strait; Feeding and summer distribution of herring and other pelagic fishes; Distribution and abundance of Hecate Strait benthos; Food-resource partitioning in four fish assemblages; Larval herring distribution in Hecate Strait; Forecasting year-class strength of herring using environment-dependent stock recruitment models; effects of transport, temperature, and stock size on recruitment of Pacific cod; Interaction between Pacific cod and herring in the Strait; Analysis of population regulation in Pacific cod.

RESUME

Tyler, A. V. (Editor). 1986. Hecate Strait Project: results of the first two years of multispecies fisheries research. Can. Tech. Rep. Fish. Aquat. Sci. 1470: 50 p.

Le projet Détroit D'Hécate de la Direction des recherches sur les pêches de la Station de biologie du Pacifique, mais sur pied en avril 1984, se poursuivra pendant cinq ans. Ce projet a pour objectif l'élaboration d'une base écologique pour la gestion des pêches de stocks mixtes dans le détroit d'Hécate. Les débarquements en provenance de cette région sont importants localement, mais faibles dans le contexte des pêches mondiales. Les faibles volumes représentent cependant un avantage du point de vue de la recherche. Ce système constitue en réalité un modèle de systèmes très étendus que l'on retrouve dans plusieurs parties du monde et dont l'étude est plus difficile, ce qui complique la gestion des pêches. Le projet est divisé en douze sous-projets de recherche connexes qui sont: l'estimation, par spectre de tailles de particules, du stock actuel de poissons pélagiques; des relevés de la répartition des groupes de poissons dans le détroit d'Hécate; la répartition du hareng et des espèces pélagiques qui lui sont associés en hiver; l'estimation de l'abondance et de la taille des espèces de saumons capturées dans le détroit; l'alimentation et la répartition d'été du hareng et d'autres espèces pélagiques; la répartition et l'abondance du benthos dans le détroit d'Hécate; la répartition nourriture-ressource chez quatre groupes de poissons; la répartition des larves de hareng dans le détroit d'Hécate; la prévision de l'importance des classes annuelles du hareng à l'aide de modèles de recrutement des stocks dépendants de l'environnement; les effets du transport océanique, de la température et de la taille des stocks sur le recrutement de la morue du Pacifique; l'interaction entre la morue du Pacifique et le hareng dans le détroit d'Hécate; et l'analyse de la régulation de la population de la morue du Pacifique.

WORK OBJECTIVES, APPROACH AND BACKGROUND

A. V. Tyler, Project Coordinator

The project is a multi-species research approach to interrelated productivity questions. The general project goal is to acquire sufficient understanding of relationships among selected species in Hecate Strait to develop a multi-species, assemblage approach to their management. Part of the project strategy is based on adaptive, assemblage-management possibilities (Tyler et al. 1982). Another approach is based on the Sheldon Spectrum and particle size dynamics (Sheldon et al. 1982). The third approach involves specific species interactions studies. Major research areas include: (A) Species interactive modelling; (B) At-sea observations, analysis, systems modelling leading to the development of assemblage fishery management; (C) A study of recruitment processes on species relevant to aims A and B, with the objective of detecting recruitment over-fishing under an adaptive assemblage management plan.

Since the Strait is highly productive of groundfish, some emphasis is being placed on these species. A substantial quantitative background on groundfish has been developed for Hecate Strait. Herring have also attracted the attention of the project planning group because of their abundance, economic importance, and possible prey relationships to groundfish species. Preliminary information suggests that the dynamics of herring must be understood in the context of predator-prey system. The time trends of herring in Hecate Strait are distinct from the trends of herring stocks in southern British Columbia.

It has been realized for several years that the potential fisheries yield of several species within a geographic region cannot be calculated by summing the maximum sustainable yields of those species. The summation is limited in its meaning because fishes can interfere with one another's productivity making it impossible for all stocks to be at maximum productivity levels year after year. Such an interaction is not accounted for in traditional yield models.

Limitations of traditional approaches to stock assessments have led to proposals for new multi-species approaches that require development and testing. Research will be carried out in the Hecate Strait Project that will set the stage for implementation of multi-species management in Hecate Strait region.

Four approaches to multi-species management are being addressed by the Project:

1. Management by key species in a fishery mix. Pacific cod may be such a key species for the overall management of the species mix taken in the trawler fishery. Trawlers in the Strait primarily take a mixture of several species of flatfish and Pacific cod. Since recruitment overfishing has often not been a problem with cold-water flatfishes in different parts of the world, including Hecate Strait (Tyler and McFarlane 1985), sustainable use of species by trawlers might be achieved by management of just Pacific cod.

2. Species interaction models. Some management decisions may revolve about specific questions answerable by modelling particular species interactions. For example, what is the cost to herring production of doubling the number of salmon feeding in Hecate Strait? A large increase in the numbers of coho salmon is a goal of the Salmon Enhancement Program. Species interaction models will be developed to develop quantitative hypotheses around this question.

3. Management by use of assemblage production units (APU). The concept and management use of an APU depends on the identification of resident assemblages of exploited fishes, and knowledge of trophic connectivity patterns within the assemblages (Tyler et al. 1982). Research in the Hecate Strait Project will characterize APUs for the region. Implementation of two approaches to APU management will be developed: (1) an equilibrium model approach and (2) a transition-state model approach. The first has a rationale based on mixed species surplus production; the second depends on early detection of recruitment overfishing, hence the need for proposed sub-projects on recruitment processes.

4. Total system yield estimates using particle size dynamics theory. Evidence has been accumulating that there is a relationship between marine animal body size and the sustainable number of animals of a particular size (Sheldon et al. 1982). Estimates of the standing stock of phytoplankton or zooplankton may lead to an estimate of the standing stock of resident, pelagic fishes. Theory has to be developed for demersal fishes, and also to account for the effect of widely migrating species on the size-spectrum.

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1. R. Dunbrack and D. M. Ware
Particle size spectrum estimation of the standing stock of pelagic fish

Trophic conversions in pelagic systems are characterized by relatively constant predator/prey size ratios. The resulting flow of biomass from small to large particles has profound consequences for the structure of pelagic ecosystems. In particular it leads to a distribution of biomass along the particle size axis which can be approximated by a simple density function of the form KW^{-b} where W is the particle mass, and K and b are the constants. The form of the biomass distributions was first investigated by Sheldon and his co-workers who found that the standing stock of particles in logarithmically equal size classes seemed to be roughly equivalent. Sheldon also pointed out that because of the simple nature of the biomass spectrum, it should, in principle, be possible to estimate the total standing stock density of particles in any mass range if that in any other mass range were known. Using this technique he was able to generate estimates of the standing stock density of commercial fish stocks from the standing stock of phytoplankton which differed little from those obtained by more direct methods.

In applying Sheldon's technique to the problem of estimating pelagic fish stocks in the Hecate Strait area we have made two modifications. Firstly, although Sheldon suggested that the value of the parameter b is approximately 1, data in Sheldon et al. (1973) suggests a somewhat higher value of 1.04 which we have used. Secondly, our initial biomass estimate was not of phytoplankton standing stock but was obtained from zooplankton samples. These were collected by vertical hauls from six stations in Hecate Strait in July 1983 and May and June 1984. These samples provided an estimate of 30 g/m^2 (wet weight) for all particles in the mass range 4.22 x/ 10^{-5} to 9.5 x 10^{-2} g. When applied to the estimation of the biomass of particles in the size range 100 to 200 g (approximate mass range of commercially caught herring) this gave a value of 1.64 g/m^2. Multiplying this by the approximate surface area of Hecate Strait and Dixon Entrance (46,252 km^2) gave an estimate of the standing stock of pelagic particles in the 100-200 g range of 76,000 tonnes. This compares favorably with the estimates of equilibrium herring standing stock of 88,000 tonnes made by Haist et al. (1985). The estimate using Sheldon's method is particularly sensitive to changes in the parameter b. For example, b values of 1 and 1.07 give estimates of 54,000 to 120,000 tonnes respectively. Future investigations will be concerned with the factors determining the value of b and the effects of fluctuations in important variables such as temperature and primary production on the shape of the particle size spectrum.

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2. J. Fargo and A. V. Tyler
Hecate Strait fish-assemblage distribution surveys.

In May 1984 the first of a series of species assemblage surveys was conducted in Hecate Strait (Fargo et al. 1984; Westrheim et al. 1984). The purpose of the surveys was to provide synoptic survey data that would lend itself to a mapping of fish assemblages available to bottom trawlers. The assemblage maps were meant to display the changes in relative abundance of species throughout Hecate Strait. Stations fished simultaneously by two survey vessels are mapped in Figure 2.1.

An agglomerative clustering method employing a Bray-Curtis dissimilarity index and group-average fusion strategy was applied to the data collected. Dendrograms from the cluster analysis of species catch composition data by weight were used to define four assemblage distribution units in Hecate Strait (Fig. 2.2). The assemblage units as mapped indicate that species are associated with depth contours in Hecate Strait. Assemblage 1 in northern Hecate Strait lies at depths of 30-70 fathoms on the Two Peaks-Butterworth fishing ground. This assemblage biomass is dominated by arrowtooth flounder with ratfish and Dover sole also accounting for significant proportions (Table 1.1). Examination of species composition data by numbers indicates that English sole is significant in this assemblage as well. Assemblage 2 encompasses most of the shallow area adjacent to Dogfish Bank to depths of about 30 fathoms. This assemblage biomass is dominated by dogfish with skate and rock sole significant as co-habitants. Examination of length frequency data indicates that Pacific halibut in this assemblage are mainly juveniles. Assemblage 3 lies adjacent to assemblage 2 at depths of 30-60 fathoms. Dogfish is significant in the biomass in assemblage 3 but not as abundant as in assemblage 2. The survey may have caught the dogfish in transition on their seasonal movement from deeper (> 50 fathoms) to shallower (< 20 fathoms) water. English sole is also a significant proportion of the assemblage. Rex sole, Pacific sanddab, and English sole all increase in relative abundance in this assemblage when abundance is measured in numbers of individuals. Examination of length frequency data indicates that Pacific halibut in assemblage 3 are mainly adults while sablefish are mainly juveniles. Assemblage 4 lies in deeper water (50-80 fath) adjacent to Moresby Gully. Rockfish make up a significant proportion of this assemblage with silvergray rockfish highest in relative abundance. Arrowtooth flounder is moderately abundant in this assemblage as well. Petrale sole was encountered only in this locality over the entire area surveyed.

The dashed lines in Figure 2.2 represent tentative boundaries for some assemblages because no survey work was done beyond these limits. Also, dendrograms from the cluster analysis indicate some degree of linkage between assemblages 1 and 3. The area between these two assemblages is untrawlable and no biological samples can be obtained from this area.

More detailed examination of assemblage composition data by size and numbers will no doubt refine these rough assemblage boundaries and assemblage characteristics. In addition, a winter survey and repeat of this summer

survey will help to quantify the amount of seasonal and annual variation in these assemblages. The stability of individual assemblages is important in determining assemblage production units and multi-species harvest plans.

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Table 1.1. Species assemblages in Hecate Strait based on trawl surveys by F/V ARCTIC OCEAN and FR/V G.B. REED May-June 1984.

Species	Relative abundance of biomass
Assemblage 1	
Arrowtooth flounder	40%
Ratfish	16%
Dover sole	10%
English sole	2%
Spiny dogfish	1%
Sablefish	1%
Assemblage 2	
Spiny dogfish	41%
Big skate	12%
Rock sole	10%
Pacific halibut	7%
Assemblage 3	
Spiny dogfish	29%
English sole	19%
Rex sole	8%
Pacific halibut	8%
Pacific cod	2%
Sablefish	2%
Pacific sanddab	2%
Assemblage 4	
Silvergray rockfish	38%
Arrowtooth flounder	19%
Spiny dogfish	8%
Petrale sole	5%
Pacific ocean perch	1%

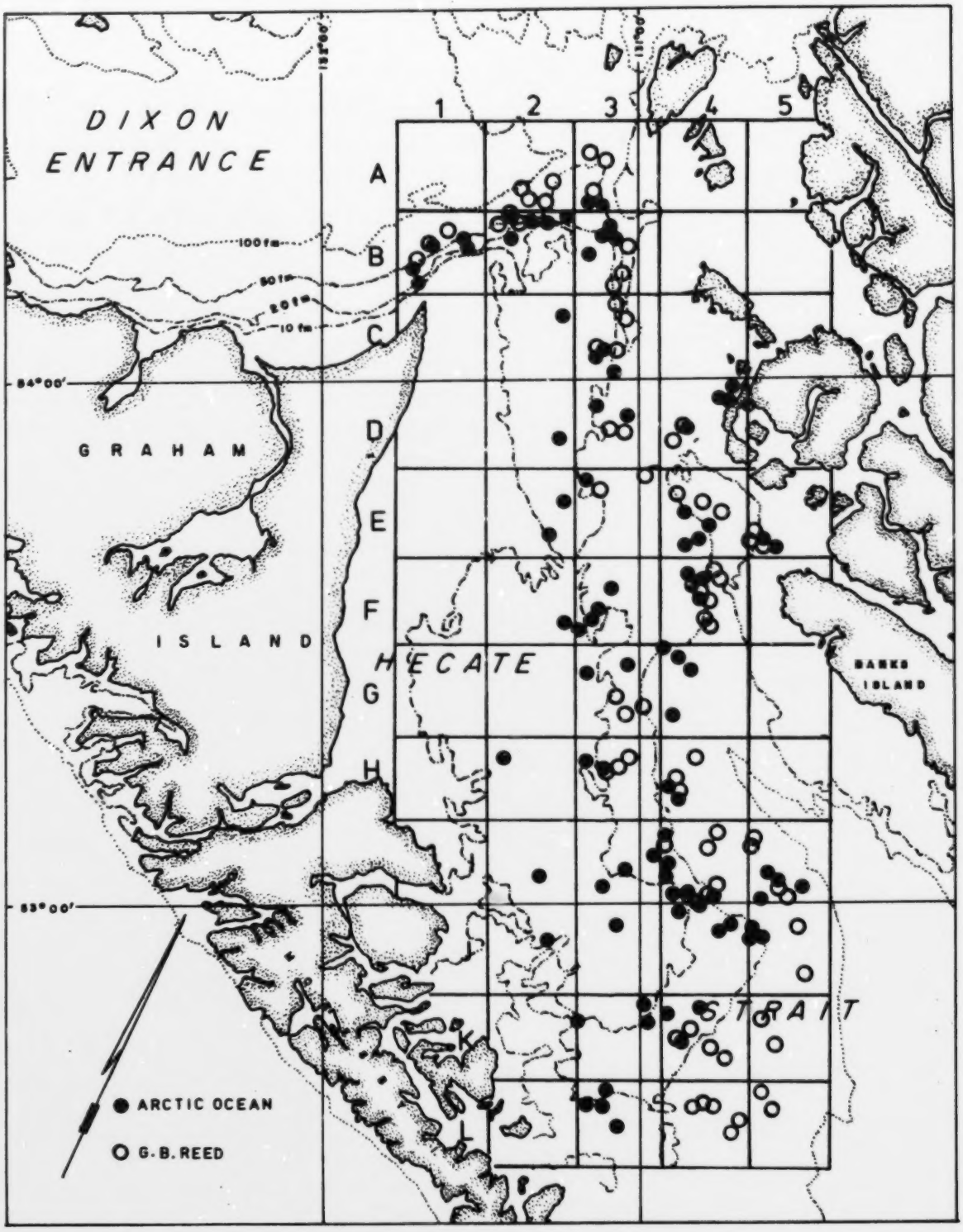

Fig. 2.1. Trawl sampling sites for the May 24 to June 17, 1984 research cruises of the ARCTIC OCEAN and G.B. REED.

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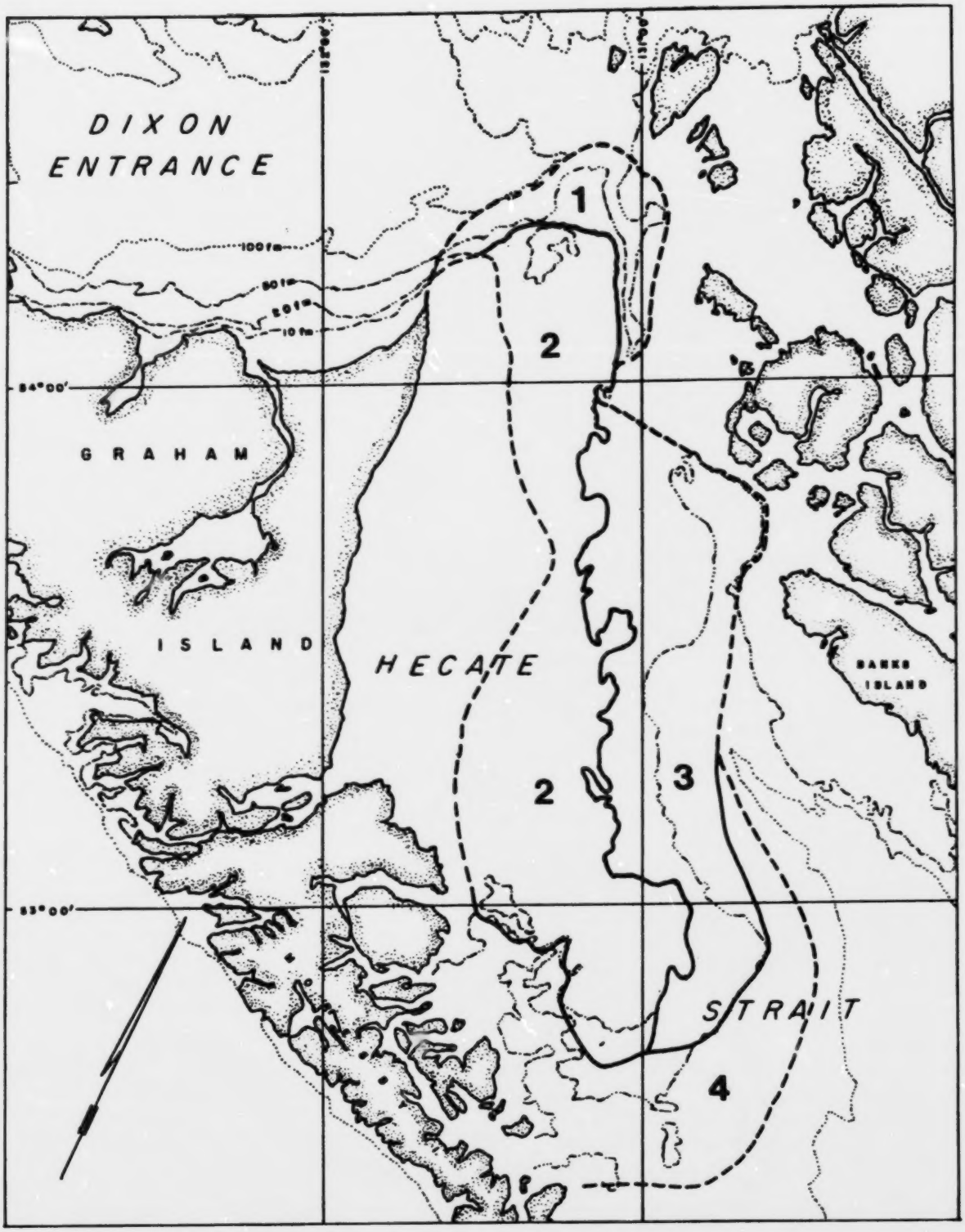

Fig. 2.2. Assemblage areas defined by statistical cluster analysis of percentage biomass abundance of fishes taken during the May 24 to June 17, 1984 cruises of the ARCTIC OCEAN and G.B. REED at sites mapped in Fig. 2.1.

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3.0 D. E. Hay, R. Kieser, and P. B. McCarter
Distribution of herring in winter

Three late fall and winter cruises made in Oct-Nov 1984, January 1985 and Nov-Dec 1985 have been conducted with the following objectives: (1) to survey broad areas and plot the main fall and winter distributions of herring in Hecate Strait and examine the stability of this distribution over time; (2) examine the feasibility of hydroacoustic assessments of herring biomass, (this required that we examine both the short-term variation in herring geographic distribution and diurnal variation in depth); (3) examine the species composition and trophic relationships of herring and other species.

Results to date indicate that winter herring distributions are predictable and are associated with major spawning distributions. The major winter concentrations are (1) the Browning Entrance area and (2) Juan Perez Sound on the southeast extreme of the Queen Charlotte Islands. Browning Entrance appears to be the major winter location for the north coast herring spawning on Porcher Island and Chatham Sound. Though it is possible that herring that spawn in Chatham Sound overwinter in locations other than the vicinity of Browning Entrance, no other large winter herring concentrations were observed in spite of extensive searching in both nearshore and offshore locations. Such searches, however, have not been made in adjacent Alaskan waters.

The specific Browning Entrance sites of herring concentrations were nearly identical between Nov 1984 and Dec 1985. The general area where herring are found is about 300 square nautical miles (10 NM x 30 NM) but within this area, there are several smaller distinct locations of about 10 square nautical miles (2 NM x 5 NM) which appear to be the most consistently occupied. It is also evident that winter herring concentrations can sometimes become highly mobile, moving within or between these sites rapidly. There is no clear indication of size, age, or sex differences among the sites, although it seems that single concentrations or schools often consist of single size- or age-groups.

The Juan Perez concentration was observed in January 1985 and again in the following December. This general location corresponds, roughly, to the largest spawning location on the Queen Charlotte Islands, extending from the northern part of Juan Perez Inlet (Darwin Inlet) south to Skincuttle Inlet (Huston Inlet). There also are some smaller, distinct winter concentrations of herring on the Queen Charlotte Islands that have been observed during these surveys and previous surveys in the 1970s. In general, there appears to be a close correspondence between the spawning distribution and winter distribution (Table 3.1) although the biological distinctness of each stock is not clear at this time.

The behavior of the overwintering herring varied between the Browning Entrance and Juan Perez Inlet. The Juan Perez fish formed dense, widespread 'skimmers', up to several nautical miles in dimension, that rose to

shallow depths at dusk and descended during dawn. In constrast, the Browning Entrance fish were more highly fragmented and were often found closer to the bottom during the dark hours. They also showed the same diurnal depth variation but it was less pronounced than the Juan Perez fish.

The factors controlling the winter distribution of herring are not clear. Proximity to nearby spawning grounds must be meaningful but there is nevertheless a broad range of possible habitats that could be used by the herring. Predator avoidance could play a role. However, pending completion of the analyses of the fish and plankton samples our preliminary finding was that herring concentrated at sites of planktonic food abundance. If so, this was unexpected because herring are generally believed to feed very little during winter months. While this may indeed be the case, it is also possible that ingestion of small quantities of food during the earlier winter months from October to December could be important as a maintenance diet. After December, when sexual maturation accelerates, the gonad nearly occupies the full body cavity so that the potential for expansion of the gut would be limited. Therefore, with this winter feeding hypothesis in mind, we are carefully examining the guts of herring collected during the last winter cruise (November and December 1985) to determine if traces of food are in herring guts. On the basis of casual observation of plankton hauls made in the vicinity of winter herring distributions, it is clear that there are planktonic food organisms in the water, mainly euphausiids. Also, examination of dogfish guts collected by trawl, revealed that many were feeding on euphausiids as well as fish.

The main factors affecting the veracity of hydroacoustic surveys of herring in winter are (1) the likelihood of finding herring in predictable, well defined locations and (2) the repeatability of the distribution findings over time. It appears that the overwintering areas are stable between years. This conclusion is based on the results of the three winter cruises during two consecutive years as well as reference to previous fall and winter surveys in the region. Confinement of herring to a few major winter holding areas precludes the necessity of having to make expensive, time-consuming geographically widespread synoptic surveys. Hydroacoustic biomass estimates also are affected by the mobility of the fish: if fish move rapidly within the winter holding areas, then attempts to survey the biomass will be difficult. On the basis of preliminary analyses, we conclude that the mobility of herring within the holding areas may be a problem but perhaps not be insurmountable. For instance, repeat hydroacoustic surveys of small, distinct concentrations show striking differences in biomass estimates made over a 24-hour cycle (Table 3.2). This variation reflects some of the problems of hydroacoustic surveys of herring; the fish cannot be detected if they move too close to the surface or bottom, or if they move into shallow water. Also, it is not known if herring can avoid the hydroacoustic vessel.

Field data for the January 1985 cruise are published (McCarter and Hay 1985).

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Table 3.1 Suggested relationship between the main winter holding areas and spawning locations in Hecate Strait and Dixon Entrance.

	Winter area	Spawning area
1.	Browning Entrance (including locations in the general area such as Edye Pass, the White Rocks grounds, etc.).	Kitkatla Inlet, north Porcher Island, Chatham Sound, including Big Bay and Port Simpson.
2.	Juan Perez Inlet, Queen Charlotte Islands (QCI).	Skincuttle Inlet and locations in the general vicinity of Juan Perez Inlet including Burnaby Island, Darwin Sound, etc.
3.	Cumshewa Inlet	Cumshewa Inlet.
4.	Skidegate Inlet.	Skidegate Inlet.
5.	Langara Island, McIntyre Bay.	Naden Harbour.

Table 3.2 The nominal biomass estimates (metric tons) from the first 24-hour survey in Browning Entrance are summarized. The estimates cover a range of 2040 to 15100 t, a ratio of 7.4. Day observations range from 8350 to 15100 t and are approximately 6 times higher than the night time estimates.

	Time					
Transect	13:59	18:23	22:09	01.54	05:40	15:34
27	931	1030	1220	429	458	698
26	3280	7430	149	612	3340	6620
25	2950	937	526	193	7600	4460
24	1190	1550	147	952	1930	1910
Sum	8350	10900	2040	2190	13300	15100
Average	Day 9625		Night 2115		Day 14200	

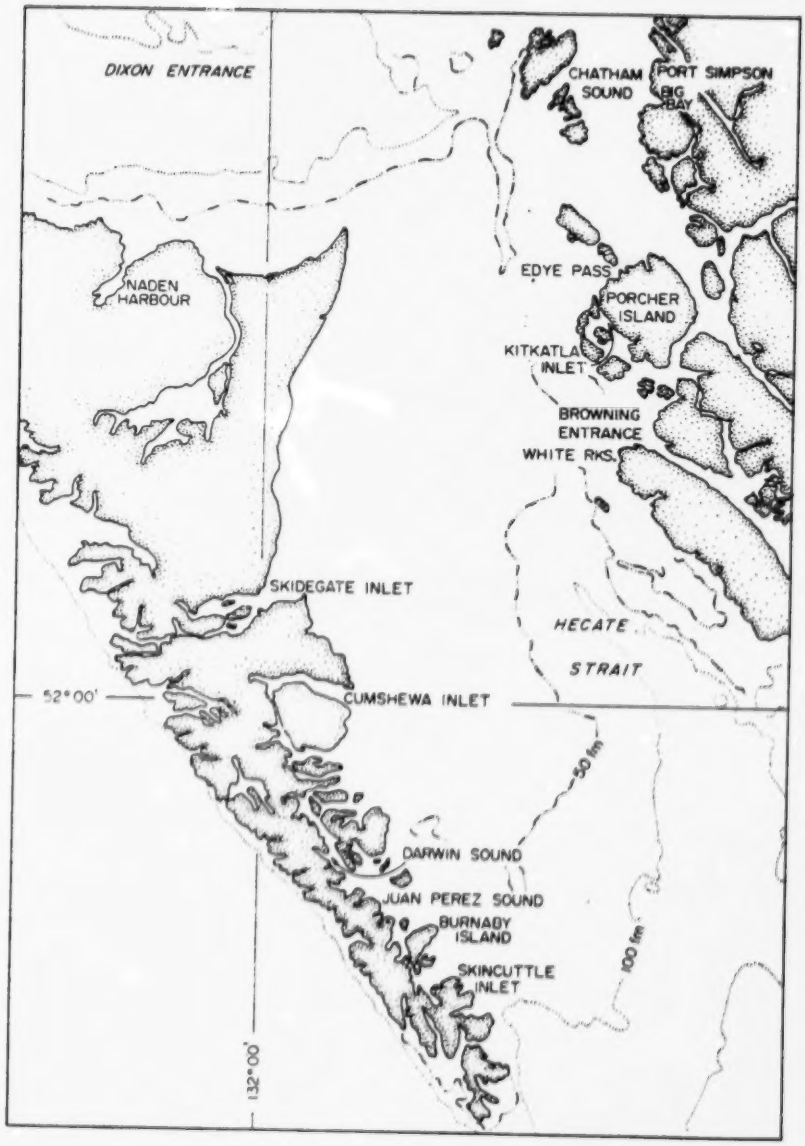

Fig. 3.1. Localities described in the text.

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4.0 M. C. Healey
Modelling juvenile salmon utilization of Hecate Strait

Juvenile salmon undoubtedly make some use of Hecate Strait as a migratory pathway and as a nursery ground. The extent to which this occurs, however, is unknown. Virtually no sampling of juvenile salmon has occurred within Hecate Strait itself, and only limited sampling has occurred in adjacent waters. Certain basic features of juvenile salmon abundance and biology during early sea life are known, however, and this knowledge permits informed hypothesizing about juvenile salmon utilization of Hecate Strait.

Numbers of young salmon entering the ocean may be estimated from the abundance of spawning stocks in each region of the coast. During their first summer of ocean life, usually within a few weeks of entering the ocean, pink, chum, and sockeye salmon undertake a rapid and directed north and northwestward migration along the coast. Rates of travel approximate 1 length-per-second (their most efficient sustained cruising speed). Chinook and coho, by contrast, disperse rather slowly from the vicinity of their natal river mouth during their first summer of ocean life. Although their direction of dispersal is also north and northwest, their migration may be much less directed than that of pink, chum, and sockeye. Growth rates during the first ocean year may be inferred from published observations made at various locations along the coast and from back calculated sizes at age derived from adult scales. Food requirements may be estimated from growth rates and rates of travel by means of metabolic equations.

An important unknown, however, is the point at which juvenile salmon from different regions of the coast turn away from shore and migrate into the open North Pacific Ocean. Do the young salmon that migrate northward out of the Strait of Georgia via Johnstone and Queen Charlotte straits continue to move northward through Hecate Strait or do they turn west and migrate into the North Pacific Ocean through Queen Charlotte Sound? To evaluate the consequences of this unknown I constructed a multicompartment model that permitted me to calculate seasonal abundance and resource requirements of juvenile salmon in Hecate Strait under different assumptions about coastal migratory behavior of juveniles of all species.

Not surprisingly, the total abundance, biomass, and food requirements of juvenile salmon summed over a year in Hecate Strait are very sensitive to assumptions about their coastal migratory behavior. If one assumes that only salmon from rivers tributary to Hecate Strait migrate through the Strait, then the population would be dominated by pink salmon during both even and odd years, with chum much less abundant and sockeye comparatively rare. If, on the other hand, one assumes that all juveniles from rivers south of Hecate Strait migrate through the Strait, then pink salmon would still be the most abundant, but both chum and sockeye would be only slightly less abundant (Table 4.1). In both instances coho and chinook would be relatively minor components of the population. Biomass and food requirements of each species present a similar picture, although the contributions of sockeye, coho and chinook tend to be relatively higher because of their larger size at time of seaward migration (Table 4.1). The difference in total biomass between the two extreme assumptions about

migratory behavior is about 20X whereas the difference in food requirements is about 10X, and the difference in numerical abundance is only about 4X (Table 4.1). This is because juveniles entering the Strait from the south are considerably larger than those produced by local tributaries, and thus contribute a large biomass, but not a correspondingly large food requirement, since their rate of increase in weight is lower than that of smaller fish.

Since the different species migrate seaward at different times, and grow and migrate northward at different rates, and since it takes time for fish from southern tributaries to reach Hecate Strait, the composition of the population in the Strait is constantly changing and is sensitive to assumptions about migratory behavior. For example, if only salmon from tributaries of Hecate Strait migrate through the Strait, then by mid-July only coho and chinook should still be present. If juveniles from southern rivers migrate northward through the Strait, however, the model predicts that in mid-July juveniles of all species from southern rivers would be moving through Hecate Strait and the population would be dominated by sockeye, with pink and chum about half as abundant, and coho and chinook a minor component (Table 4.1). Consequently, assumptions about juvenile migratory routes may be tested by examining the species composition of young salmon in Hecate Strait during July and August.

Table 4.1. Predictions of abundance, biomass and food requirements for each species from the migration model when extreme assumptions about juvenile migratory routes are made. Less extreme assumptions about migratory routes produce intermediate predictions.

		Assumptions about which juvenile salmon use Hecate Strait		
Measure	Species	Only juveniles from tributaries of Hecate Strait utilize Strait	All juveniles from waters south of Hecate St. utilize St.	
Abundance (Fish-days X 10^6)	Sockeye	58	3289	
	Pink (o)	1050	4251	
	Pink (e)	2599	7518	
	Chum	663	3516	
	Coho	184	490	
	Chinook	81	134	
Biomass (kg X 10^4)	Sockeye	66	9547	
	Pink (o)	360	10142	
	Pink (e)	1172	11120	
	Chum	350	5690	
	Coho	446	11026	
	Chinook	101	615	
Food requirements (kg x 10^4)	Sockeye	5	580	
	Pink (o)	72	1051	
	Pink (e)	233	1436	
	Chum	48	516	
	Coho	51	574	
	Chinook	13	45	
			Odd yr	Even yr
% composition of Hecate Strait salmon population predicted for week 28 (July 15-21)	Sockeye	0	53	51
	Pink (o)	0	22	-
	Pink (e)	0	-	24
	Chum	0	24	24
	Coho	90	0.3	0.3
	Chinook	10	0.7	0.7

5.0 D. E. Hay and P. B. McCarter
Feeding and summer distribution of herring and other pelagic fishes

A cruise was conducted July-August 1985 to examine summer distributions of herring and stomach contents of herring and associated midwater fishes. The objectives were: (1) determine if a proximity relationship exists between known, over-wintering, inshore herring aggregations, and dispersed summer distributions found offshore along the 50-fathom edges of Hecate Strait; (2) identify fish predators of young herring and other trophic relationships during their summer feeding period.

The survey area included Chatham Sound, McIntyre Bay, Two Peaks, Butterworth Edge, Warrior Ground, Freeman-Whiterock Ground, SW Bonilla, Horseshoe, Ramsay-Reef Island Grounds, and SE/NE Goose Island Bank. Herring were caught on the Two Peaks (40-50 fath), Ramsay Is. (60-75 fath) and SW Horseshoe (40-50 fath) grounds. Herring schools were scattered and close to the bottom during the day and dispersed throughout the water column during the night. One hundred plankton bongo samples and 13 fish samples including seven species of midwater fishes are being processed in the lab. These species are: Pacific herring (Clupea harengus pallasi), walleye pollock (Theragra chalcogramma), widow rockfish (Sebastes entomelus), redstripe rockfish (Sebastes proriger), eulachon (Thaleichthys pacificus), spiny dogfish (Squalus acanthias), and arrowtooth flounder (Atheresthes stomias). A brief summary is presented in Table 5.1. Age-length data, stomach and herring distribution data will be integrated with previous offshore herring cruises. Heavy plankton layers may have been responsible for many of the echogram traces encountered on this cruise and should be confirmed when analysis of the plankton samples is completed.

Table 5.1. Trawl catch and sounding summary for August 1985. Relative abundance based on catches and number of schools sounded (High ***; Medium **; Low *; Nil -).

Areas sounded (area sounded and fished)	Herring	Walleye pollock	Rockfish	Eulachon (juvenile)	Dogfish and arrowtooth flounder
Chatham Sound	-	-	-	*	-
McIntyre Bay	*	** (Juveniles)	-	-	-
Two Peaks	*** (Adult)	*** (Adult)	*	*	-
Butterworth Edge	-	-	*	-	-
Warrior Ground	-	-	-	-	-
Freeman-Whiterocks	*	*	** (S. entomelas)	*	*
SW Bonilla	-	-	-	-	-
S Banks Is.	-	-	**	-	-
SW Horseshoe	* (Adult)	-	-	-	-
Ramsay Is.	** (Adult)	*	** (S. proriger)	-	-
Reef Is.	-	-	*	-	*
SE/NE edge Goose Bank	-	-	*	-	-

6.0 D. F. Moore and R. O. Brinkhurst
Preliminary report on the Hecate Strait benthos sub-project

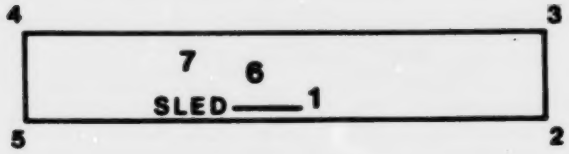
The benthic sampling design is based on a stratified design for substrate type and depth. Choice of this design reduces (and may even eliminate) the variability in species composition and population abundance estimates that result from sampling communities representative of different substrates or depths. Five representative quantitative samples, stratified for depth and substrate, are needed to characterize the benthos in each area. A minimum of five replicate benthic grab samples is required for statistical anlysis of benthic data.

A single sample was taken with a Smith-MacIntyre grab at each of five stations in each area: one on each of the four corners, and one in the center. Five replicate grabs were taken at each of two other stations within the area; the substrate was different at each of these stations. An epibenthic sled was used to obtain a qualitative sample, across 0.4 nautical mile of bottom (10-minute haul), near station #1 (Fig. 6.1).

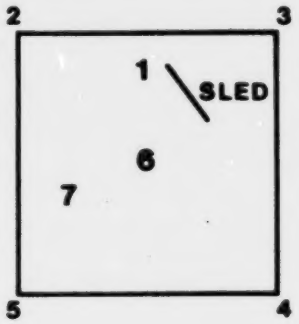
Three areas were sampled on the first of the three cruises (June 1985) and four areas were sampled on each of the next two cruises (September 1985, January 1986). In each area, 15 grab samples and one sled sample were obtained. The areas A, B, C, and D are described further in this report by Saunders and Tyler.

The preliminary results of the taxonomic identifications from the June 1985 cruise, indicate the presence of over 128 species of polychaete, over 25 species of amphipod, over 30 species of gastropod, and over 40 species of pelecypod. These were the most abundant groups represented in the samples.

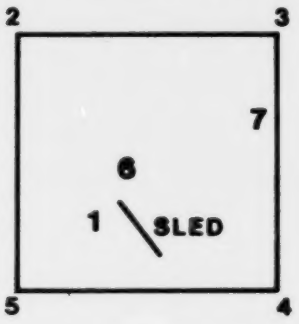
AREA A 1×6 (Nautical Miles)^2



AREA B 3×3 (N.M.)^2



AREA C 3×3 (N.M.)^2



AREA D 3×3 (N.M.)^2

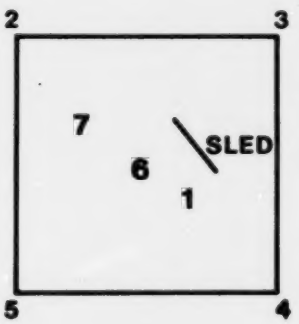


Fig. 6.1. Benthos sampling scheme. The numbers on the rectangles indicate sample sites. Distances are in nautical miles (N.M.). The location of the four areas in Hecate Strait is shown in Figure 7.1.

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7.0 M. W. Saunders and A. V. Tyler
Food-resource division study

A primary goal of this study is to establish and compare the patterns of food resource division among abundant groundfish species within assemblage production units (see Tyler. Work objectives, approach, background, this document) in Hecate Strait.

During June 1984 we looked at the species composition of research trawl hauls throughout Hecate Strait (see Fargo and Tyler. Assemblage distribution surveys). By applying cluster analysis to these data we identified three assemblages of groundfish species. On the basis of these results we selected three sites of nine square nautical miles deemed to be representative of the assemblages (Fig. 7.1). A fourth area (D) was added to complement Area C from a sub-assemblage region with greater quantities of English sole.

We exised stomachs from samples of fish from research trawl hauls made by the R/V G.B. REED during June 1985 at Areas A, B, and D; during September 1985 at Areas A, B, C, and D; and during February 1986 at Areas A, B, C, and D. A total of 2382 and 2759 stomachs respectively, were collected and preserved for later laboratory analysis during June and September (Tables 1, 2). During June 1985 we carried out diel sampling in Area A with hauls completed every six hours over a 24-hour period, and diel sampling in Areas B and C during September 1985.

Laboratory analysis of stomach contents is currently underway. Prey items are being identified to species, when possible, and information on digestion state, prey size, and prey weight is being recorded. An investigation is being conducted of shifts in diet with increasing predator size for each species of predator.

Benthic grab and epibenthic sled samples were collected by staff of the Ocean Ecology section of the Institute of Ocean Sciences, Patricia Bay, during the June and September 1985 cruises. These samples will provide an index of prey availability, and will allow comparisons of prey abundance among stations.

Future sampling will be conducted during June 1986. When complete, the series of samples should provide an in-depth picture of food resource utilization, how it varies with season and the effect of seasonal inhabitants such as dogfish and Dover sole.

Some hypotheses addressed by this study regarding predator-prey relationships are as follows:

Hypothesis 1. Regarding relative abundance in stomachs and sediment. Prey relative abundance in the stomachs is the same as abundance in the sediment.

Implies that prey is not selected. If not true, then prey is selected.

Hypothesis 2. Regarding quantities of a prey item consumed. Abundance of a single prey taxon in stomachs and in sediment is independent.

Implies that quantity eaten is not responsive to quantity in sediment. Alternatively, when there is more in the sediment there is more in the stomachs. Quantity eaten is a response to quantity present.

Hypothesis 3. The greater the abundance of a prey species in the substrate, the greater the number of predator species that take the prey species as a principal prey.

Implies that diet overlap is due to superabundance of prey.

Hypothesis 4. As predator size increases, so does prey size.

If true, the implication is that selection by prey size is a resource partitioning mechanism.

Hypothesis 5. Hypothesis (4) is not influenced by size spectrum of prey in substrate.

If true, then the resource partitioning mechanism is strong and obligatory.

Table 7.1. Full stomachs collected and preserved, by species, during the G.B. REED cruise of the Food-resource division study, June 7-17, 1985.

Species	No. of stomachs
Male spiny dogfish	64
Female spiny dogfish	304
Big skate	1
Black skate	29
Longnose skate	25
Ratfish	298
Pacific cod	64
Walleye pollock	145
Lingcod	1
Eulachon	0
Staghorn sculpin	0
Sablefish	104
Sebastes elongatus	0
S. alutus	89
S. babcocki	5
S. brevispinus	16
S. flavidus	15
Speckled sanddab	67
Pacific sanddab	0
Arrowtooth flounder	382
Petrale sole	2
Rex sole	211
Flathead sole	21
Pacific halibut	37
Rock sole	168
Dover sole	118
English sole	113
Sand sole	101
Butter sole	0
Starry flounder	2
Total	2382

Table 7.2. Full stomachs collected and preserved, by species, during the G.B. REED cruise of the Food-resource division study, September 23 to October 4, 1984.

Species	No. of stomachs
Male spiny dogfish	210
Female spiny dogfish	409
Big skate	110
Black skate	3
Longnose skate	4
Ratfish	97
Pacific cod	236
Walleye pollock	48
Lingcod	12
Eulachon	10
Staghorn sculpin	2
Sablefish	107
Sebastes elongatus	4
S. alutus	48
S. babcocki	45
S. brevispinus	31
S. flavidus	25
Speckled sanddab	2
Pacific sanddab	28
Arrowtooth flounder	375
Petrale sole	54
Rex sole	207
Flathead sole	77
Pacific halibut	101
Rock sole	139
Dover sole	190
English sole	85
Sand sole	96
Butter sole	4
Total	2759

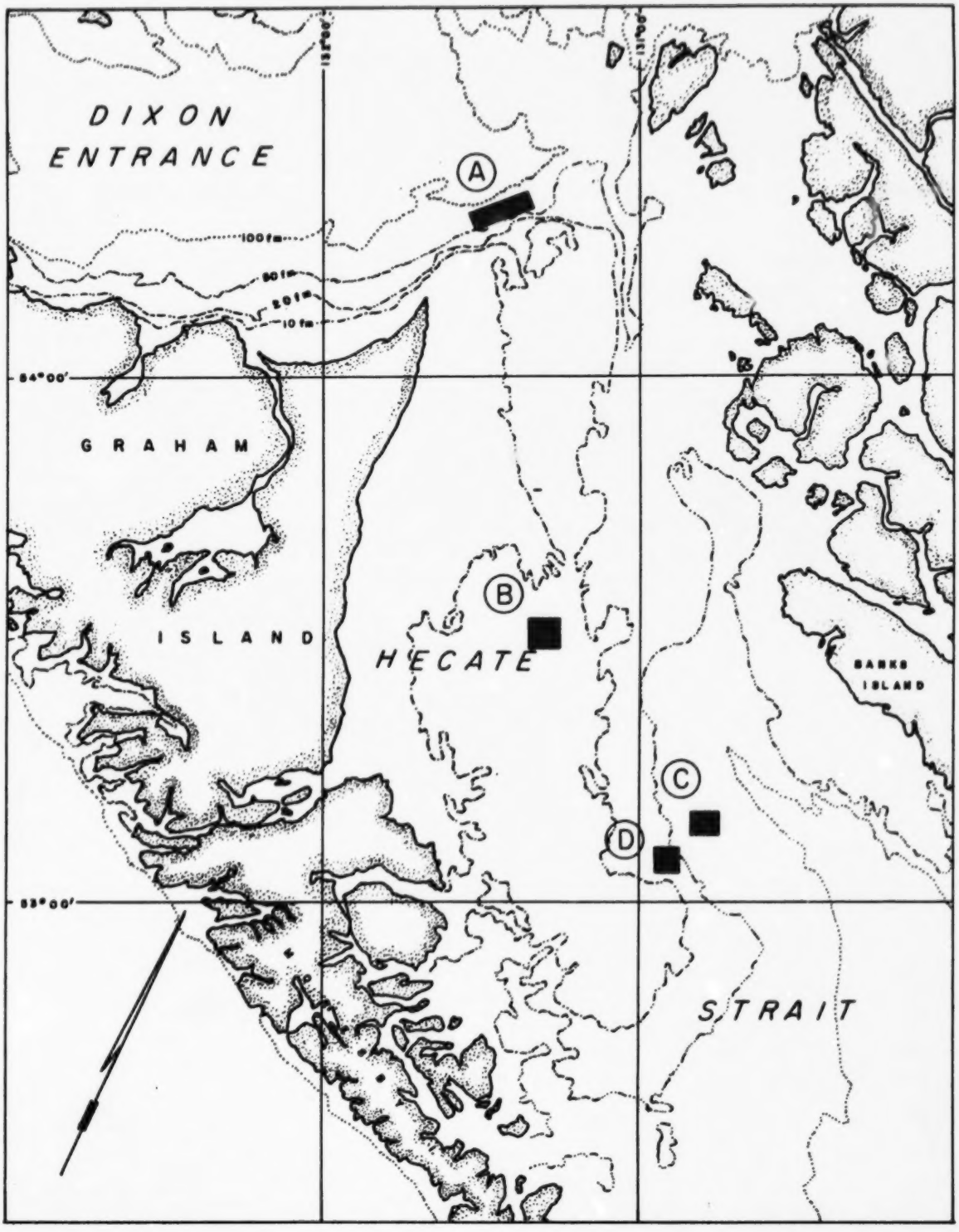

Fig. 7.1. Stomach sampling locations; A, B, C, D.

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8.0 D. E. Hay
Larval herring distribution in Hecate Strait

Surveys of larval herring and other ichthyoplankton were conducted in the general vicinity of the three major spawning areas in Hecate Strait: (1) Kitkatla and Porcher Island; (2) Big Bay to Port Simpson in Chatham Sound; (3) the southern Queen Charlotte Islands, particularly Juan Perez and Skincuttle inlets. A total of 414 plankton hauls were made using 0.5 m nets (350 microns) hauled from the G.B. REED and 0.2 m bongo nets hauled from 6 m Boston whalers. The G.B. REED examined locations in deeper offshore sampling stations; the whalers sampled near-shore stations, not accessible to the G.B. REED because of their shallow water or close proximity to shore.

The samples include a 24-hour series conducted to examine diurnal variation in depth, ichthyoplankton species composition and vulnerability to capture. Laboratory analyses of the samples should be completed by late February (1986) and the data will be submitted for keypunching then. The analyses include species identification, counts of larval numbers of all species and estimates of larval size numbers. Medusae were counted and identified by M. Arai, University of Calgary. Pending completion of the laboratory analysis, there are some tentative conclusions and observations that can be made at this time. In general, larval herring appear to be more abundant in near-shore locations. On the mainland side of Hecate Strait, the larval herring distribution was continuous between the southwest edge of Porcher Island, north to Portland Inlet, in Chatham Sound. This area encompasses the two largest spawning locations in extreme northern British Columbia waters - centered in Kitkatla (Porcher Island) and Big Bay (Chatham Sound). This continuous larval distribution is evidence that fish for these two spawning locations may mix extensively during their early stages. Therefore, the two separate spawning locations may not be genetically distinct. No herring larvae were found in the middle of Hecate Strait, indicating that herring larvae on the mainland side of the Strait do not mix with those of the Queen Charlotte Islands. Larval sandlance (Ammodytes), however, was found in nearly all locations. Dense concentrations of larval herring also were found in the vicinity of known large spawning areas in the Queen Charlotte Islands. There the distribution of larval herring was less uniform than on the mainland side, with substantial differences in abundance over short distances. Preliminary results from a replicate survey in May 1986 indicate a similar pattern of larvae herring distribution in all of the areas, although 1986 larval herring abundance was conspicuously lower in the Queen Charlotte Islands.

Pacific herring probably comprise the largest biomass of any fish species in Hecate Strait, with the possible exception of the sandlance (Ammodytes). From the work in this project, however, we tentatively conclude that since herring larvae are generally confined to near-shore waters, not far from earlier spawning sites, they probably have little or no impact on the trophic dynamics of larger organisms in the open waters of Hecate Strait.

9.0 M. Stocker

Forecasting year-class strength of Pacific herring using environment-dependent Ricker stock-recruitment models

There are complex mechanisms that cause fluctuations in recruitment of Pacific herring (Clupea harengus pallasi). The magnitudes of recruitment have been highly variable over the period of 1951-1982. This study is an attempt to forecast year-class strengths in the face of varying environmental conditions that affect the relationship between spawning stock and recruitment. I postulate that deviations from average recruitment are mainly attributable to changes in density-independent mortality due to environmental conditions. A modification to the Ricker spawning stock-recruitment model is used to forecast recent herring year-class strengths.

Ricker (1954) described the spawning stock-recruitment relationship as: $R = a * S * \exp(-b S)$; where R is the recruitment, S is spawning stock, a is the density independent mortality, and b is related to density-dependent mortality and specifies the replacement spawning stock size. It is assumed that deviations from predicted recruitment are attributable to changes in the a parameter over time, and a is considered to be a function of environmental conditions: $a'(t) = g[X1(t),X2(t),\ldots,X_m(t)]$; where $X_i(t)$ is an environmental factor at time t (i.e.., sea surface temperature affecting density-independent mortality at time t (Tang 1985). Substituting the second equation into the first equation yields a modified Ricker stock-recruitment model, which forms the basis for forecasting herring year-class strengths.

To select significant environmental factors for inclusion in the model, I used the technique of "exploratory correlation" (Ricker 1975; Stocker et al. 1985). I correlated the recruitment estimates from the age structured model (Haist et al. 1985) with monthly mean values of environmental factors thought important in the early life history of Pacific herring.

Spawning stock and recruitment data (Haist et al. 1985) for the Prince Rupert District have been fitted to obtain estimates for the modified Ricker stock-recruitment model using multiple linear regression. The linear model incorporating May-September mean sea surface temperature, mean of January and February Ekman transport, and January mean sea level explained 45.4% of the variance in environmental conditions. The parameter estimates were used with the most recent estimates of spawning stock size, and environmental variables to forecast year-class strengths as follows:

Prince Rupert District

Year-class	Strength	3-yr-old biomass range
1983	good	1986: 17,000-20,000
1984	good	1987: 8,000-10,000

The range of the 3-yr-old biomass (tonnes) is based on historical year-class strengths corresponding to the frequency plot of herring recruitments (Fig. 8.1a). Frequency is the number of years that recruitment levels occurred in the given interval in the 32-year study period. Forecast year-class strengths for 1983 and 1984 are indicated with arrows.

Poor	lowest 25% of years
Average	middle 50% of years
Good	highest 25% of years

Using the above model, fluctuations in herring recruitment are explained as depending on both the spawning stock size and the environmental conditions (Fig. 8.1b).

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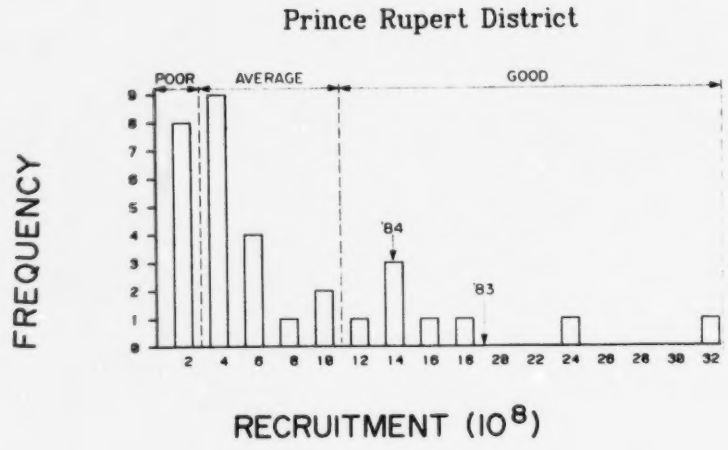
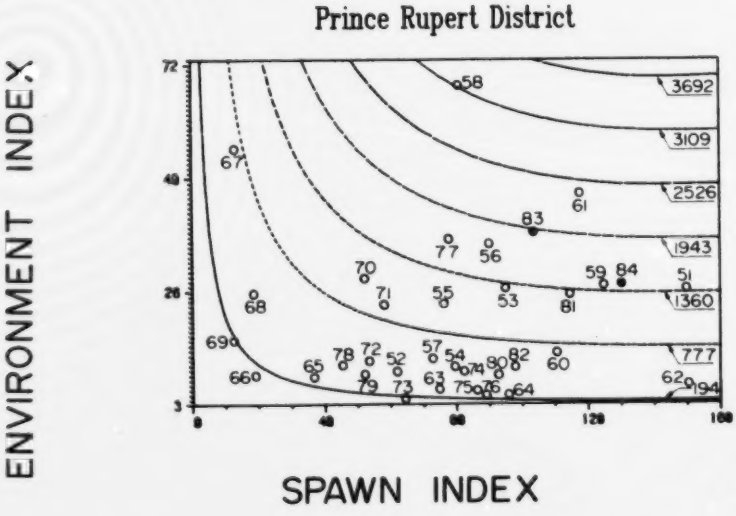


(a)



(b)

Fig. 9.1a. Frequency plot of herring recruitments and forecast (↓) year-class strengths for Prince Rupert District.

9.1b. Recruitment isopleths of environmental conditions (a'$_t$) on spawning stock size; recruitment: (o) observed, and (●) forecast.

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10. A. V. Tyler and S. J. Westrheim
Effects of transport, temperature, and stock size on recruitment of Pacific cod (Gadus macrocephalus)

During January, February, and March of each year the newly spawned cohort of Pacific cod is in the water in Hecate Strait, British Columbia, Canada as demersal, adhesive eggs and probably bathypelagic larvae. During this period, the water is isothermal from surface to bottom, and characterized by northward water-mass transport. With a 23-year time series of landings-per-unit effort and hydrographic data we examined the hypotheses that stronger northward transport in some years decreased year-class strength by carrying larvae away from Hecate Strait; that water temperature influenced survival of eggs and larvae; and that stock size influenced recruitment (Tyler and Westrheim, In press). Multi-variate linear regression did not give a significant fit to the data, but a multi-variate, second-order equation explained 67% of the variance of the recruitment time-series. Transport accounted for most of the variance, with temperature and stock sizes each accounting for lesser amounts, in that order. Temperatures in the above-average range (6.5-7.7°C) enhanced recruitment, while stronger advection decreased recruitment. Decreased stock sizes for the range in the model increased recruitment.

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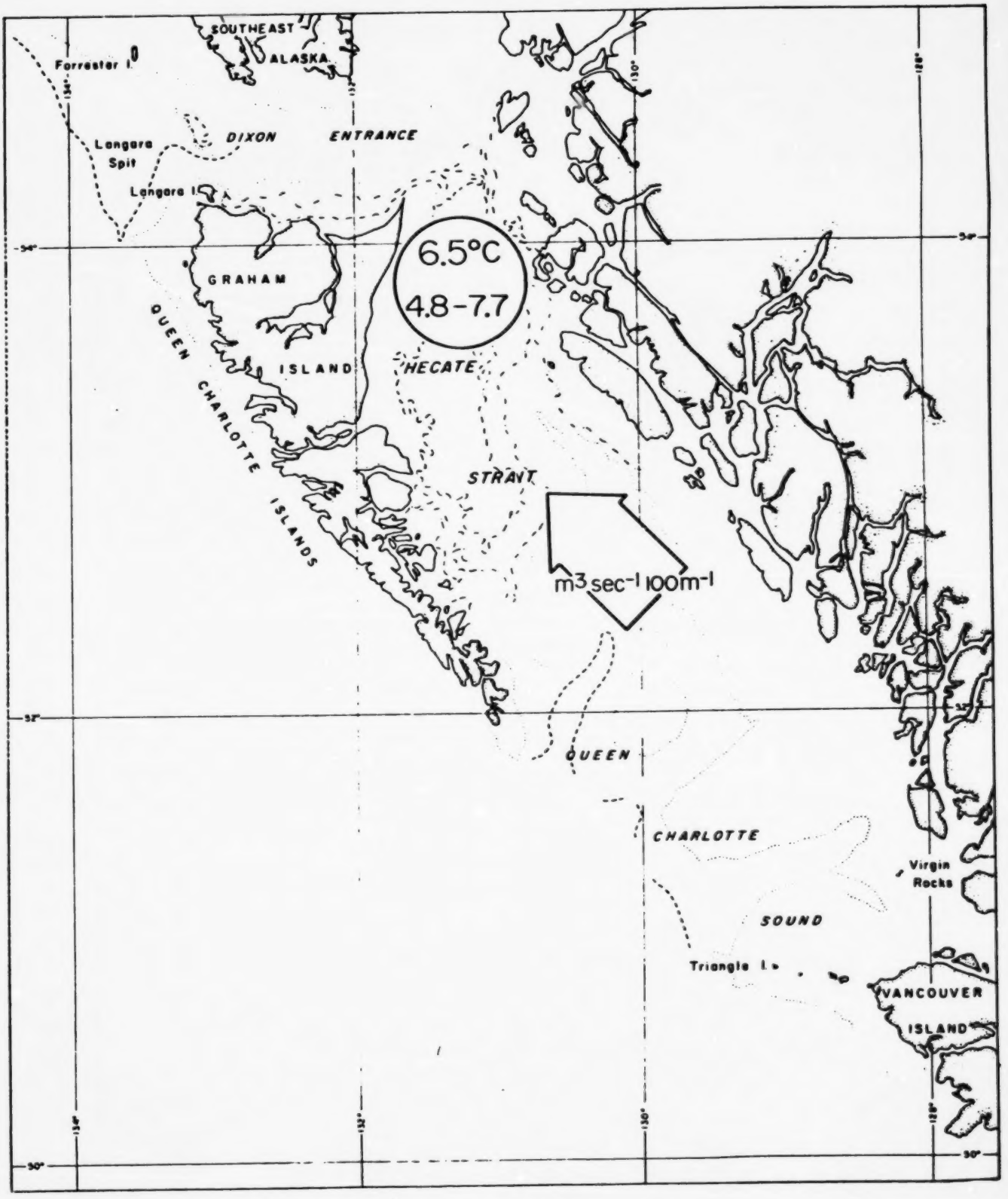

Fig. 10.1. Graphical representation of physical factor hypotheses supported by the statistical fit against year-class strength. February temperatures at the higher end of the range for the study period (4.8-7.7°C) increase survival. The mean for the period was 6-5°C. 2. Stronger northward advection flushes larvae from the area occupied by the population (Hecate Strait).

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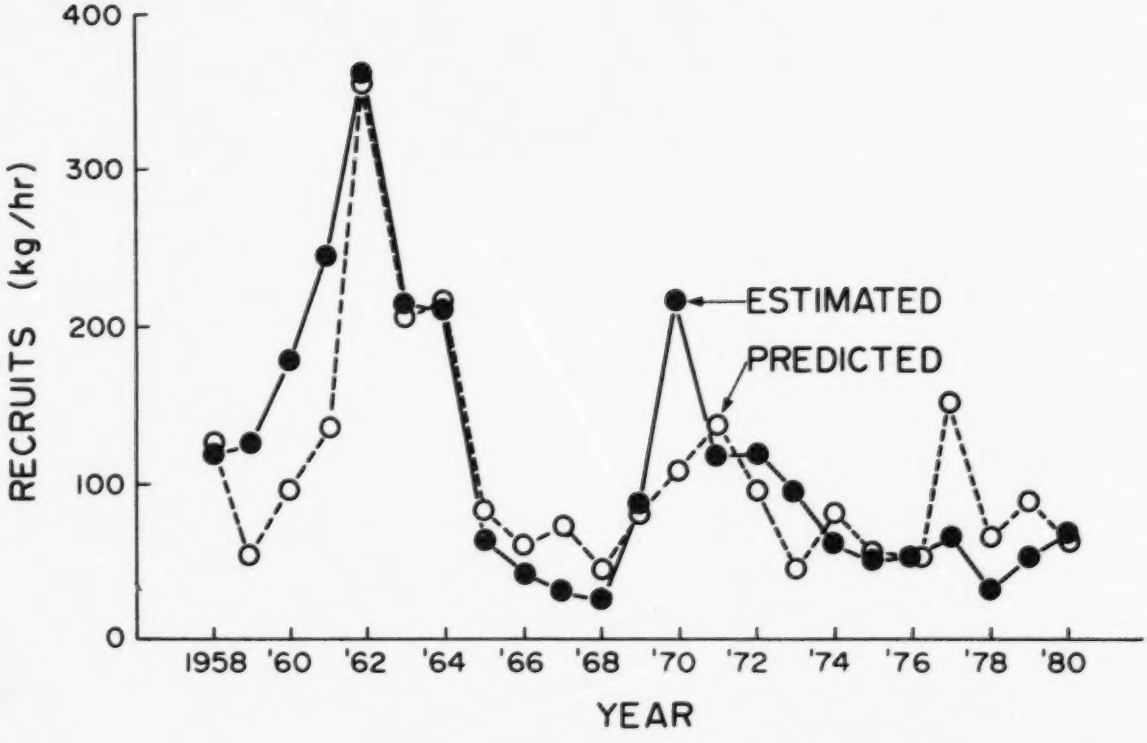

Fig. 10.2. Observed and predicted recruitment indices (CPUE of age-3 fish as kg/hr) for the study period. Recruitment is plotted on the year of birth.

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11.0 C. Walters, M. Stocker, A. V. Tyler, and S. J. Westrheim Interaction between Pacific cod (Gadus macrocephalus) and herring (Clupea harengus pallasi) in Hecate Strait

Pacific cod and herring in the Hecate Strait have shown fluctuations consistent with the hypothesis that herring recruitment rates are strongly influenced by cod predation. Regression analyses of herring juvenile survival, as measured by log recruits per herring spawner, on Pacific cod abundance indicate that the cod may cause an instantaneous mortality rate averaging around 0.75 yr^{-1}, with each cod consuming several hundred herring (Walters et al. 1986). Somewhat lower estimates of herring consumption per cod were expected on the basis of stomach contents data, but the discrepancy may well be due to systematic underestimates of cod abundance. Cod recruitment rates are positively correlated with herring abundance, but it is impossible to determine from historical data whether this correlation reflects predator-prey interdependence or the impacts of older cod on their own offspring, since cod and herring abundances are inversely correlated. It is also possible that a physical oceanographic factor influences the two species in an opposite manner. If peak cod abundances during the late 1950s were partly responsible for the herring fishery collapse of the 1960s, management of the two species should be coordinated to reflect the possibility of similar events in the future.

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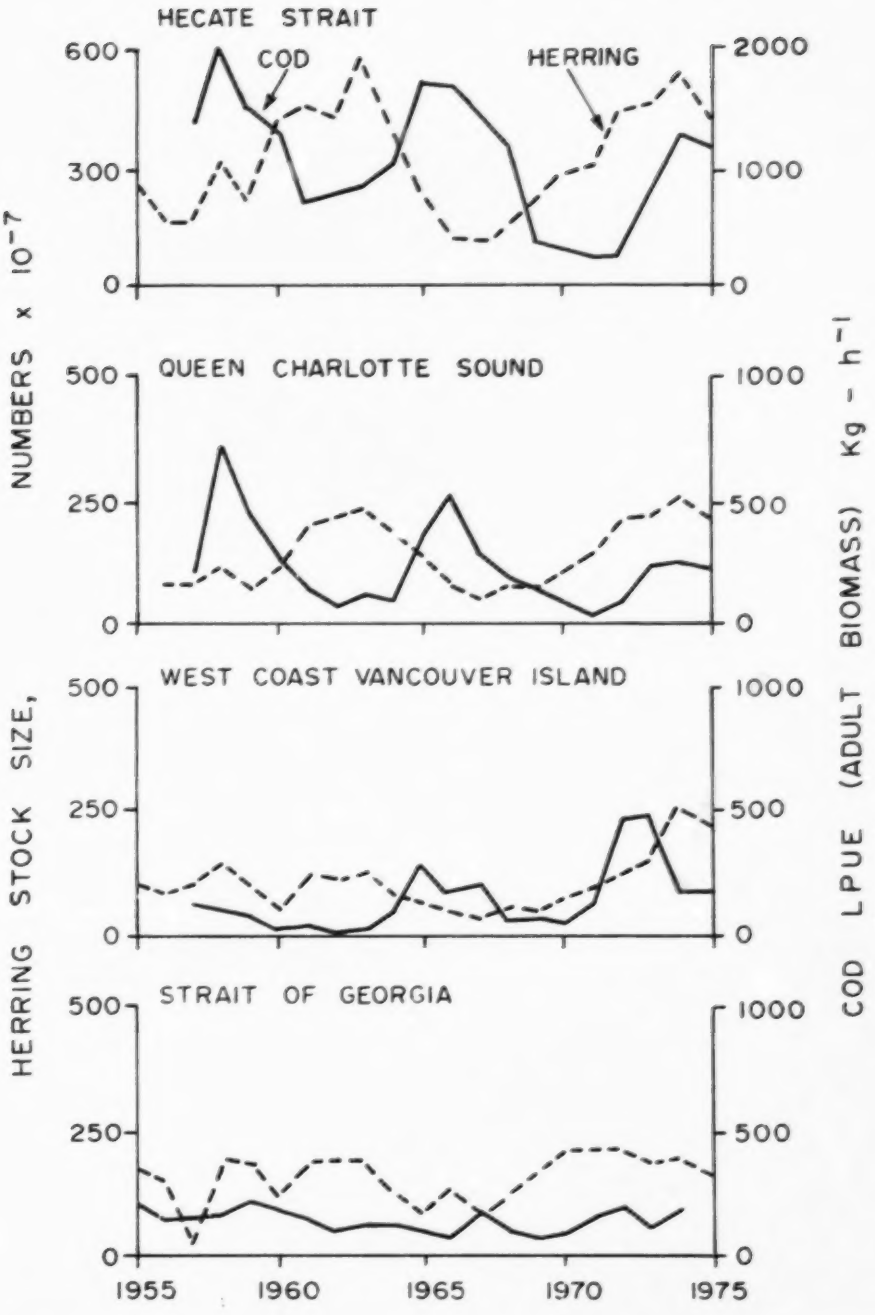

Fig. 11.1. Estimates of adult herring stock size compared to adult cod stock size (landings per unit effort) for various regions of the B.C. Coast, from data in Haist and Stocker (1984) and Westrheim and Foucher (1985). Measures for both species include fish age-3 and older. Cod catch regions are as named. Hecate Strait (Areas 5C-D) herring include Queen Charlottes and North Coast stocks. Queen Charlotte Sound (Areas 5A-B) herring is the central coast stock, West Coast Vancouver Island (Areas 3C-D). "Strait of Georgia" includes fish from Johnstone Strait (Area 4B).

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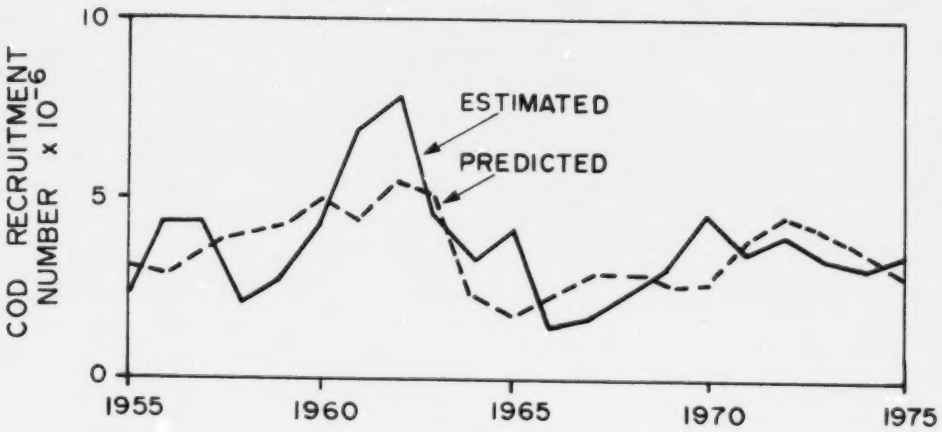

Fig. 11.2. Prediction of cod recruitment using Ricker stock-recruit relation plus herring recruitments of past years. The trajectory labelled 'estimated' is from cohort analysis. The trajectory labelled 'predicted' is from the model developed in this study.

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12.0 D. Welch and R. P. Foucher
Analysis of natural population regulation in Hecate Strait Pacific cod

Population size and productivity of Pacific cod (Gadus macrocephalus) has been strongly influenced by the highly variable levels of recruitment that have been observed since at least the beginning of studies on this population in the late 1950s. Two recent papers (Walters et al. 1986; Tyler and Westrheim in press) have evaluated alternative mechanisms for determining part of this recruitment variability, the first examining whether concomitant changes in herring population size could be plausibly related to subsequent cod recruitment levels, and the second showing that a statistical relationship could be demonstrated between recruitment levels and several physical oceanographic variables.

Our purpose was to examine more closely the effect of the cod's population size on its own reruitment, first by looking at how recruitment was historically related to stock size in the Pacific cod using a recently developed filtering methodology (Welch 1986). Secondly, we intended to partition the gross density-dependent regulation revealed by this analysis between different aspects of the cod life history (maturity, fecundity, and prerecruit survivorship) which could plausibly regulate recruitment levels and thus influence population productivity.

Our filtering results showed that about one-third of the total variability in recruitment could be identified as not being due to density-dependent factors, and was therefore attributable to either environmental influences or to errors in accurately estimating annual recruitment levels. Comparison of stock (measured as annual egg production) and recruitment time series showed evidence of an inverse relationship between these two population characteristics: at high adult population sizes recruitment was on average low, and at low stock sizes recruitment was high. This type of relationship implies strong internal density-dependent regulation. To investigate the factors determining this regulation we had intended to establish the level of variation in rates of maturity and fecundity with population size, and then to attribute the residual density-dependence to variation in prerecruit survival. However, our preliminary analysis showed that very large year-to-year changes in rates of maturation occur in Hecate Strait Pacific cod, but the limited maturation data as yet available has hindered the partitioning of the gross density-dependent regulation between population components for the bulk of the history of the fishery. Our current work is concentrating on establishing rates of maturation over a wider range of years, and production and recruitment.

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